NATIONAL ADVISORY COMMITTEE
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

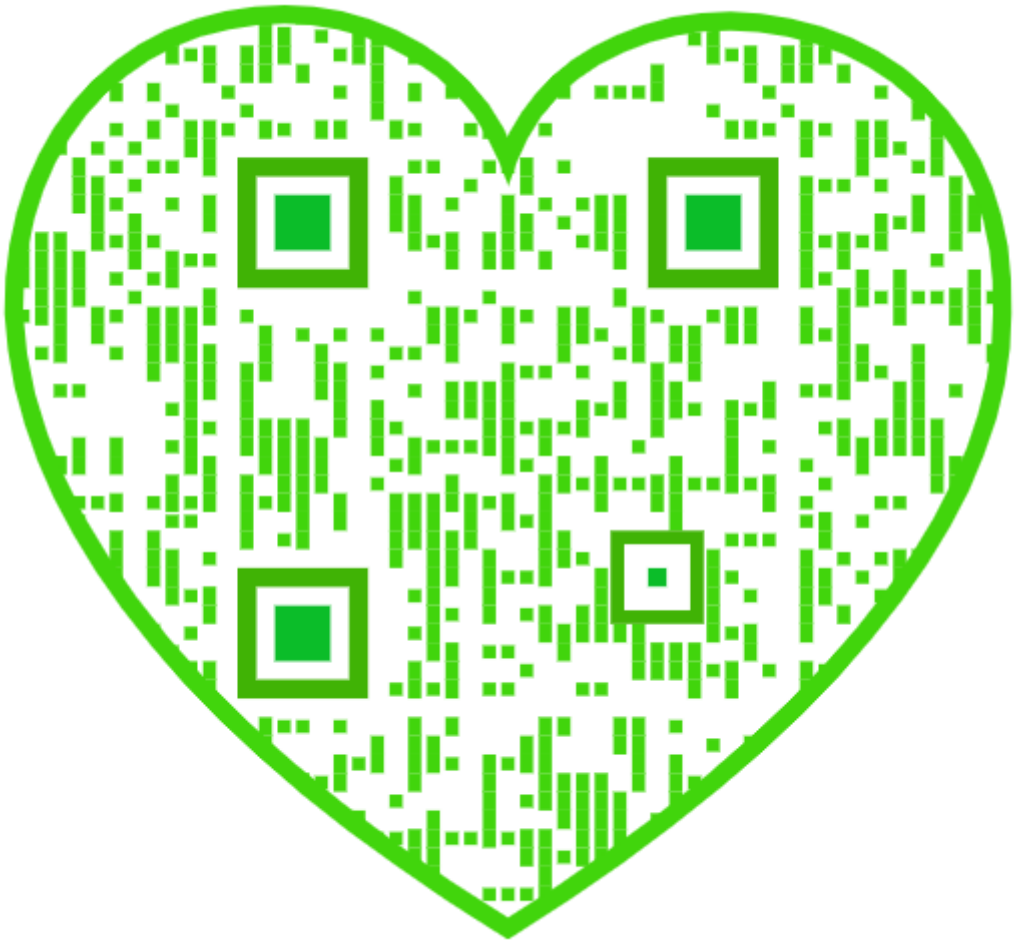
No. 106

NOTES ON AERODYNAMIC FORCES - III.

The Aerodynamic Forces on Airships.

By Max M. Munk.

July, 1922.



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Summary.

The results of the two preceding notes are applied to airships and checked with wind tunnel tests.

1. The Air Forces Observed on an Airship Model.

In the first two notes of this series I discussed the dynamical forces of bodies moving along a straight or curved path in a perfect fluid. In particular I considered the case of a straight and very elongated body and as special case again if bounded by a surface of revolution.

The hulls of modern rigid airships are mostly surfaces of revolution and rather elongated ones too. The ratio of the length to the greatest diameter varies from 6 to 10. With this elongation, particularly if greater than 8, the relations valid for infinite elongation require only a small correction, only a few percent, which can be estimated from the case of ellipsoids for which the forces are known for any elongation. It is true that the trans-

verse forces are not only increased or decreased uniformly, but also the character of their distribution is slightly changed. But this can be neglected for most practical applications, and especially so since there are other differences between theoretical and the actual phenomena.

Serious differences are implied by the assumption that the air is a perfect fluid. It is not, and as a consequence the air forces do not agree with those in a perfect fluid. The resulting air force is by no means a resulting moment only; it is well known that the airship hull experiences both a drag and a lift, if inclined. The discussion of the drag is beyond the scope of this note. The lift is very small, less than one percent of the lift of a wing with the same surface area. But the resulting moment is comparatively small too, and thus it happens as it appears from model tests with hulls, that the resulting moment about the center of volume is only about 70% of that expected in a perfect fluid. It appears however that the actual resulting moment is at least of the same range of magnitude and the contemplation of the perfect fluid gives therefore an explanation of the phenomenon. The difference can be explained. The flow is not perfectly irrotational but there are free vortices near the hull, especially at its rear end, when the air leaves the hull. They give a lift acting at the rear end of the hull and hence decreasing the unstable moment with respect to the center of volume. What is perhaps more important, they produce a kind of induced downwash, diminishing the effective angle of attack and hence the unstable moment.

This refers to airship hulls without fins, which are of no practical interest. Airship hulls with fins must be considered in a different way. The fins are a kind of wings and the flow around them, if they are inclined, is far from being even approximately irrotational and their lift is not zero. The circulation of the inclined fins is not zero and as they are arranged in the rear of the ship, the vertical flow induced by the fins around the hull is directed upwards if the ship is nosed up. Therefore the effective angle of attack is increased and the influence of the lift of the hull itself is counteracted. For this reason it is to be expected that the transverse forces of hulls with fins in air agree better with these in a perfect fluid. Some model tests to be discussed now confirm this.

These tests give the lift and the moment with respect to the center of volume at different angles of attack and with two different sizes of fins. Compute the difference between the observed moment and the expected moment of the hull alone, and divide the difference by the observed lift. The apparent center of pressure of the lift of the fins results. If this center of pressure is situated near the middle of the fins, and it is, it can be inferred that the actual flow of the air around the hull is not very different from the flow of a perfect fluid. It follows then that the distribution of the transverse forces in a perfect fluid gives a good approximation of the actual distribution and not only for the case of straight flight under consideration, but also if the ship moves along a circular path.

The model tests which I proceed to use were made by Georg Fuhrmann in the old Göttingen wind tunnel and published in the Zeitschrift für Flugtechnik und Motorluftschiffahrt, 1910. The model, represented in Fig. 1, had a length of 1145 mm., a maximum diameter of 188 mm., and a volume of 0.0182 cu.m. Two sets of fins were attached to the hull, one after another; the smaller fins were rectangular, 6.5 × 13 cm., and the larger ones, 8 × 15 cm. $(\text{Volume})^{2/3} = 0.069$ sq.m. In Fig. 1, both fins are put in. The diagram in Fig. 2 gives both the observed lift and the moment with respect to ρV, expressed by means of absolute coefficients. They are reduced to the unit of the dynamical pressure and also the moment is reduced to the unit of the volume, and the lift to the unit of $(\text{Volume})^{2/3}$.

Diagram Fig. 3 shows the position of the center of pressure computed as described before, and expressed as fraction of the entire length. The two horizontal lines represent the leading and the trailing end of the fins. It appears that for both sizes of the fins the curves nearly agree, particularly for greater angles of attack at which the tests are more accurate. The center of pressure is situated at about 40% of the chord of the fins. I conclude from this that the theory of a perfect fluid gives a good indication of the actual distribution of the transverse forces. Due to the small scale of the model, the agreement may be even better with actual airships.

2. Remark on the Required Size of the Fins.

The last examination seems to indicate that the unstable moment of the hull agrees nearly with that in a perfect fluid. Now the actual airships with fins are statically unstable, but not much so, and for the present general discussion it can be assumed that the unstable moment of the hull is nearly neutralized by the transverse force of the fins. I have shown that this unstable moment is $M = (\text{Volume})\ (k_2 - k_1)\ V^2 \frac{\rho}{2} \sin 2\alpha$, where $(k_2 - k_1)$ denotes the factor of correction due to finite elongation. Its magnitude is discussed in the first note of this series. Hence the transverse force of the fins must be about $\frac{M}{a}$ where a denotes the distance between the fin and the center of gravity of the ship. Then the effective area of the fins, that is, the area of a wing giving the same lift in a two-dimensional flow follows:

$$\frac{(\text{Volume})\ (k_2 - k_1)}{a}$$

Taking into account the span b of the fins, that is, the distance of two utmost points of a pair of fins, the effective fin area S must be

$$\frac{(\text{Volume})\ (k_2 - k_1)}{a} \times \frac{1 + 2\frac{S}{b^2}}{\pi}$$

This area S however is greater than the actual fin area. Its exact size is uncertain but a far better approximation than the fin area is obtained by taking the projection of the fins and

the part of the hull between them. This is particularly true if the diameter of the hull between the fins is small.

If the ends of two airships are similar, it follows that the fin area must be proportional to (Volume)/a or, less exact, to the greatest cross section rather than to $(\text{Volume})^{2/3}$.

This refers to circular section airships. Hulls with elliptical section require greater fins parallel to the greater plan view. If the greater axis of the ellipse is horizontal, such ships are subjected to the same bending moments for equal lift and size, but the section modulus is smaller, and hence the stresses are increased. They require, however, a smaller angle of attack for the same lift. The reverse holds true for elliptical sections with the greater axes vertical.

3. The Airship in Circular Flight.

If the airship flies along a circular path, the centrifugal force must be neutralized by the transverse force of the fin, for only the fin gives a considerable resultant transverse force. At the same time the fin is supposed nearly to neutralize the unstable moment. I have shown now in the previous note that the angular velocity, though indeed producing a considerable change of the distribution of the transverse forces, and hence of the bending moments, does not give rise to a resulting force or moment. Hence the ship flying along the circular path must be inclined by the same angle as if the transverse force is produced during a rectilinear flight. From the equation of the transverse force

$$\text{Vol } \rho \frac{V^2}{R} = \frac{\text{Vol } (k_2 - k_1)\ V^2 \frac{\rho}{2} \sin 2\alpha}{a}$$

it follows that approximately the angle is

$$\alpha \sim \frac{a}{R} \frac{1}{k_2 - k_1}$$

This expression in turn can be used for the determination of the distribution of the transverse forces due to the inclination. The resultant transverse force is produced by the inclination of the fins. The rotation of the rudder has chiefly the purpose of neutralizing the damping moment of the fins themselves.

From the last relation follows the distribution of the transverse forces due to the inclination

(1) $$\frac{dS}{dx} V^2 \frac{\rho}{2} \frac{2a}{R} dx$$

This is only one part of the transverse forces. The other part is due to the angular velocity, it is approximately

(2) $$k_2 \frac{2x}{R} \frac{dS}{dx} V^2 \frac{\rho}{2} dx + (k_2 + \sin \alpha) \frac{V^2 \rho}{R} S\, dx,$$

as proven in the previous note. Another secondary term, [illegible] mentioned in the second note, can be neglected. The first term in (2) together with (1) gives a part of the bending moment. The second term in (2) (having the opposite direction as the first one and as the centrifugal force) is almost neutralized by the centrifugal forces of the ship and gives additional bending moments not very considerable either. It appears then that the ship experi-

ences smaller bending moments when creating an air force opposite to the centrifugal force than when creating the same transverse force during a straight flight. For ships with elliptical sections this cannot be said so generally. The second term in (2) will then less perfectly neutralize the centrifugal force, if that can be said at all and the bending moments become greater in most cases.

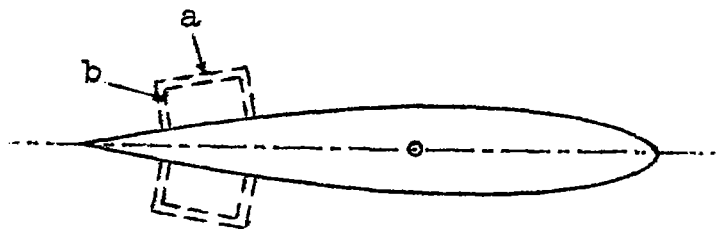
a
b

Fig. 1.

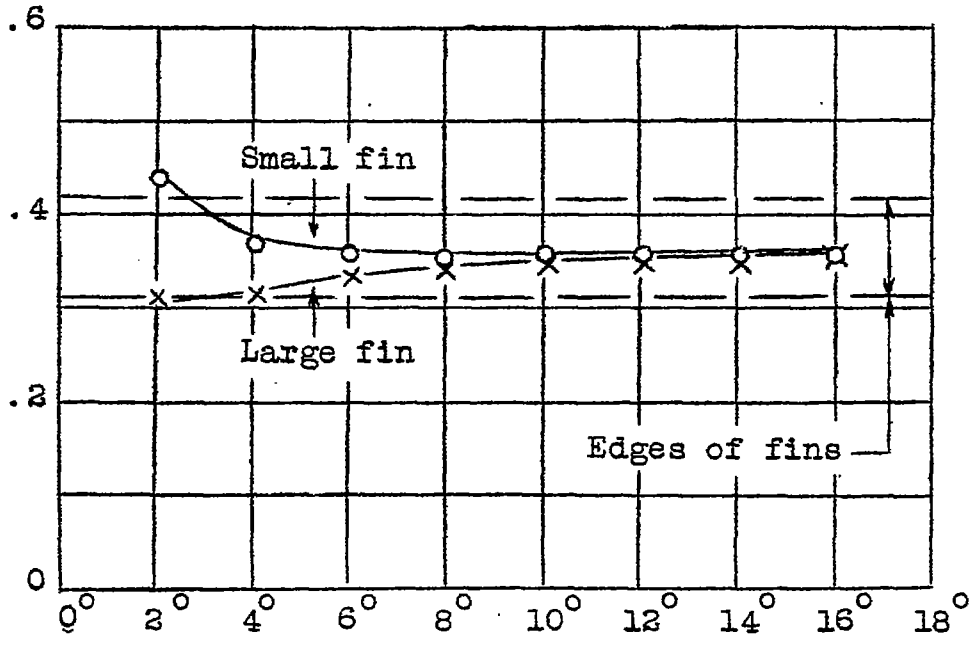
.6
.4
.2
0
Small fin
Large fin
Edges of fins
0°
2°
4°
6°
8°
10°
12°
14°
16°
18°
Angle of attack.

Fig. 3.

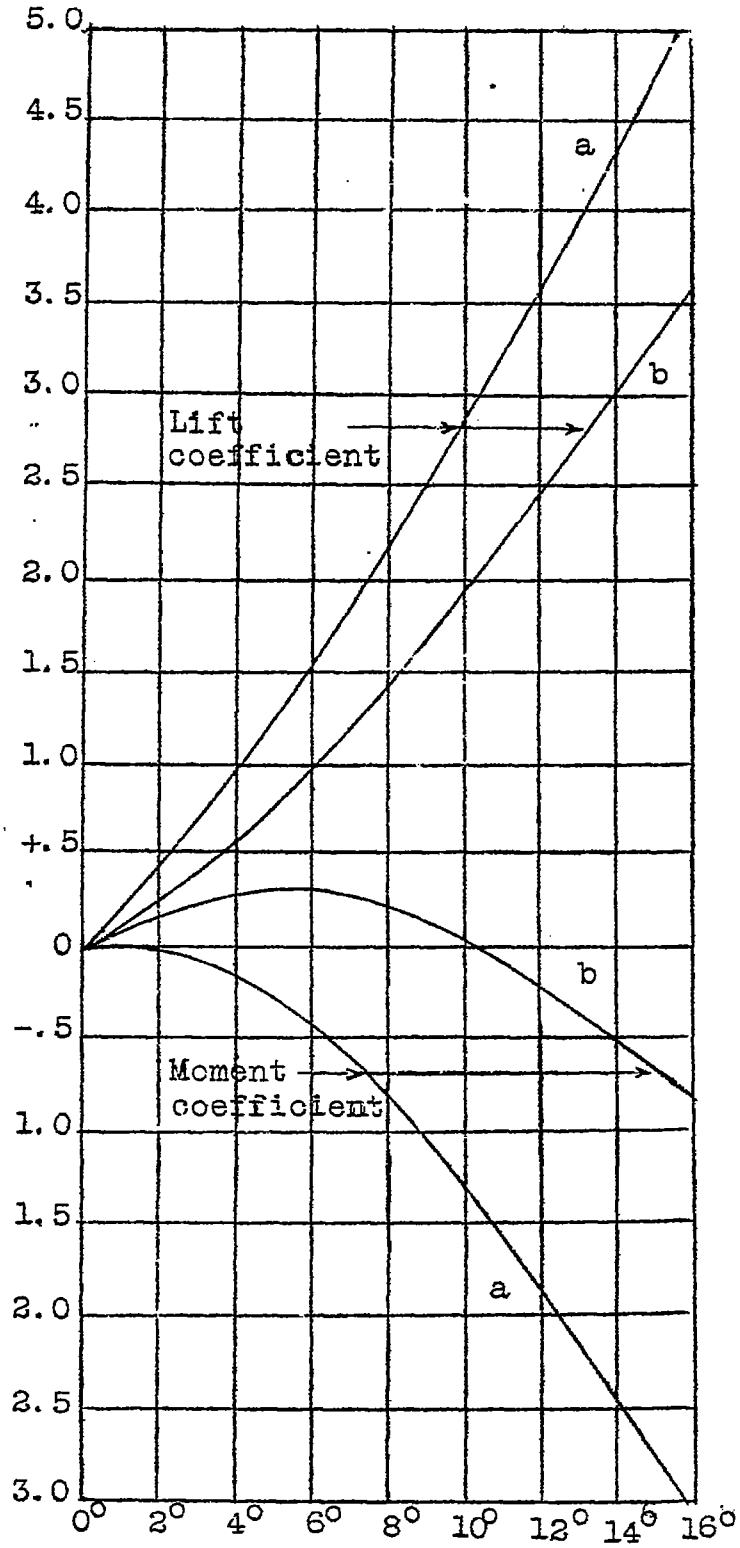
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
+.5
0
-.5
1.0
1.5
2.0
2.5
3.0
a
b
Lift coefficient
b
Moment coefficient
a
0°
2°
4°
6°
8°
10°
12°
14°
16°
Angle of attack.

Fig. 3.